

An Integrated Isotope Geochemistry Study of Diagenetic Cements in Brent Reservoir Sandstones, Hild Field, North Sea : Implication for the Origin of Diagenetic Waters

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Introduction

Diagenetic transformations in sandstones can dramatically affect porosity and permeability, thus impacting on reservoir quality. In order to optimize exploration-production strategies in a petroleum province, it is essential to understand diagenetic processes that occurred within a reservoir. Such a work was undertaken for the Brent sandstones of the Hild Field, North Sea, in the Diamap research project partly funded by the European Union. The aim was to reconstruct precisely the nature, conditions and timing of diagenetic transformations, and decipher the origin of fluids involved in diagenetic processes. To this effect, a detailed isotopic study was conducted on diagenetic cements, and integrated with burial, petrography and fluid inclusion data.

Background information

The Hild field is located in the Norwegian sector of the northern North Sea, on the western flank of the Viking Graben (Fig. 1). The structure is a tilted fault block generally dipping to the west. The main reservoirs are the sandstones of the Tarbert and upper Ness Formations in the Middle Jurassic Brent Group. They presently occur at maximum burial depths of 3.8 to 4.3 km subsea, temperatures of 140 to 155°C and overpressures of 35-40 MPa. The Hild Brent sandstones have been submitted to intense diagenetic alteration (Canham et al., 2001). Early diagenetic cements include minor siderite and pyrite, followed by abundant (up to 40%) precipitation of intergranular non-ferroan calcite (NFC) in the structural high. Late diagenetic transformations are more extensive and widespread. They include, in chronological order: vermicular kaolinite (K1); platy illite (I1); a first episode of quartz cementation as overgrowths (Q1); a first episode of hydrocarbon migration associated with precipitation of ferroan calcite (FC); extensive dissolution of detrital feldspar grains and diagenetic NFC cement locally; blocky dickite (K2); a second episode of quartz cementation (Q2); pore-bridging fibrous illite (I2); and a main episode of foil filling (around 35-10 Ma).

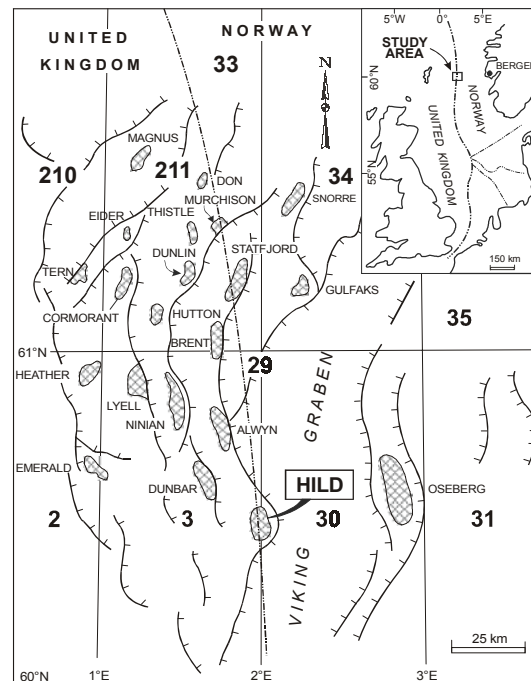


Fig. 1 : Location map of the Hild field

Analytical results

Carbonate cements ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$, $^{87}\text{Sr}/^{86}\text{Sr}$) - NFC exhibits highly variable $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ values, ranging from -10 to -3 ‰ PDB for $\delta^{18}\text{O}$ and -25 to -10 ‰ for $\delta^{13}\text{C}$. In contrast, $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ values for FC are more consistent, ranging from -15 to -12 ‰ for $\delta^{18}\text{O}$ and -6 to -3 ‰ for $\delta^{13}\text{C}$ for most samples. In $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ coordinates (Fig. 2), NFC values exhibit a distinct linear trend of decreasing $\delta^{18}\text{O}$ with increasing $\delta^{13}\text{C}$, which intercepts the compositional field for FC. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are highly radiogenic and range from 0.7111 to 0.7195. They show no particular trend with depth in any well, and are systematically more radiogenic for FC (0.713-0.719) than for NFC (0.711-0.714).

Quartz overgrowths ($\delta^{18}\text{O}$) - $\delta^{18}\text{O}$ values of quartz overgrowths, as determined by SIMS oxygen isotope microanalysis (Girard et al., 2001), range from 17 to 25 ‰ SMOW. The two successive episodes of quartz cementation, readily distinguishable under cathodoluminescence, exhibit distinct average isotopic compositions of 23.0 ‰ for Q1 and 19.5 ‰ for Q2.

Clay cements ($\delta^{18}\text{O}$, δD) - Vermicular kaolinite (K1) and platy coating illite (I1) could not be analyzed for isotopes as pure separates were not available. Dickite (K2) $\delta^{18}\text{O}$ - δD values are very consistent within the field. $\delta^{18}\text{O}$ values range from 13 to 15 ‰, averaging 14.0 ‰ ± 0.7 . δD values range from -65 to -51 ‰, averaging -57 ‰ ± 5 . Similarly, pore-bridging illite (I2) show very consistent $\delta^{18}\text{O}$ - δD values, averaging 13.5 ‰ ± 0.2 for $\delta^{18}\text{O}$ and -66 ‰ ± 5 for δD . Compared to $\delta^{18}\text{O}$ - δD values reported for diagenetic kaolinite, dickite and illite from Brent reservoirs in other fields of the northern North Sea, diagenetic clays in Hild show are characterized by a much greater intra-field isotopic homogeneity (Fig. 3).

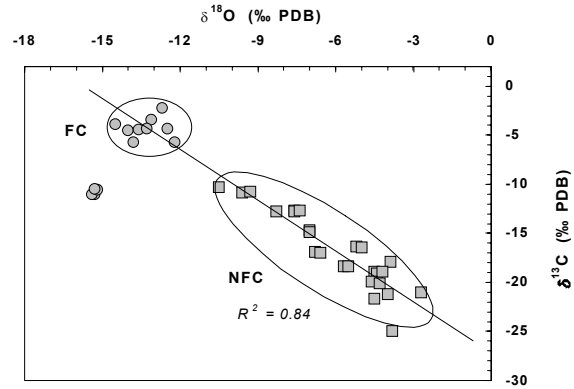


Fig. 2 : $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ values of NFC and FC cements. Solid line is first order regression through NFC data.

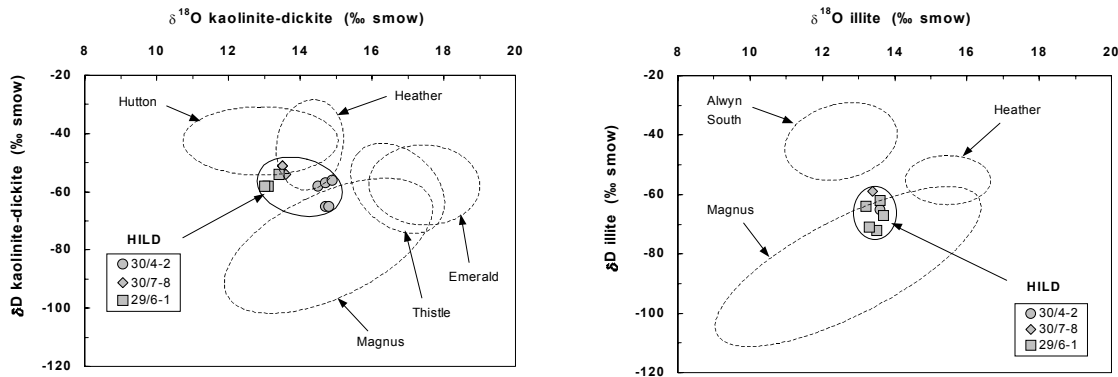


Fig. 3 : Isotopic compositions of diagenetic dickite and illite from the Hild Brent. Comparison with other fields from the northern North Sea.

Discussion and conclusions

Fluid inclusions data provide formation temperatures of about 100-110°C for Q1 quartz, 115-125°C for FC cement and 125-135°C for Q2 quartz. No fluid inclusion data are available for NFC, K2 dickite and I2 illite. However, formation temperatures of the later cements can be constrained from their position in the diagenetic sequence and from burial history to be around 20-70°C for NFC, 110-130°C for K2, and 130-150°C for I2. Combining these temperatures with isotope data permitted to reconstruct the isotopic composition of diagenetic waters from which the successive cements formed. This is shown in the $\delta^{18}\text{O}$ - δD plot of Fig. 4 along with isotopic compositions of relevant waters (sea water, meteoric water...).

The data indicate that early NFC cement formed from brackish-marine connate water, or slightly ^{18}O -enriched waters most likely expelled from the underlying Dunlin shales at shallow depth (<2 km). Late diagenetic dickite, quartz and illite cements, which developed at greater depths (2.5-4.3 km) and temperatures (100-150°C), formed from distinctly ^{18}O -enriched, D-depleted waters, isotopically similar to present-day formation water (Fig. 4). Such isotopic compositions

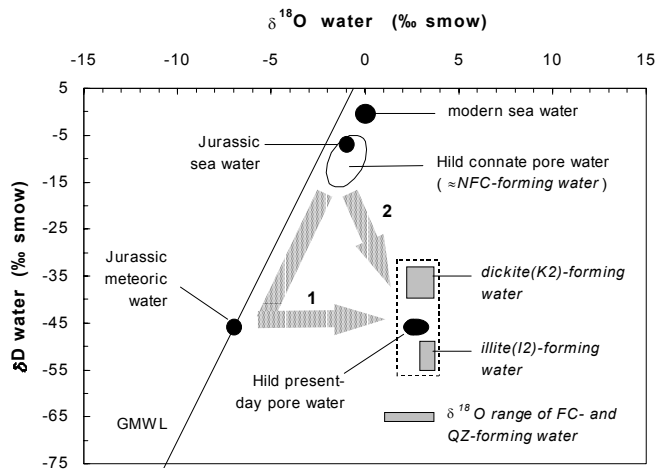


Fig. 4 : Reconstructed $\delta^{18}\text{O}$ - δD values of Hild diagenetic waters and comparison with relevant waters. GMWL = global meteoric water line. See text for comments on evolution paths 1 and 2.

are typical of evolved diagenetic waters which have undergone significant water-rock interaction. They are very different from those of Hild connate water (mixed sea water and meteoric water, Fig. 4). Two scenarios depicted as paths 1 and 2 in Fig. 4 can be considered to explain the isotopic evolution of Hild pore water. Path 1 requires pervasive flushing of the Brent with meteoric water followed by extensive dissolution of early NFC cement in closed-system conditions to increase pore-water $\delta^{18}\text{O}$ up to present values. Path 2 reflects mixing of connate water with evolved basalinal waters

introduced in the reservoir prior and/or in association with hydrocarbons. The second scenario is best supported by geological, petrographical and isotopic constraints. Such basalinal waters most likely represent compactional waters expelled from deeply buried shales, possibly in the East Shetland Basin, but mainly in the deep parts of the close-by Viking Graben.

The results of our study are in general agreement with diagenetic models previously developed in the northern North Sea. However, in contrast to many of the fields located on the East Shetland platform, the most distinctive feature of diagenesis in Hild resides in the absence of evidence for any major contribution of meteoric water.

References :

- Canham A.C., Hill S., Sommer F., Lacharpagne J.-C., Girard J.-P. and Johansen H., 2001, *J. Sed. Res.*, *submitted*.
Girard J.-P., Munz I.A., Johansen H., Canham A.C. and Hill S., 2001, *Chem. Geol.*, *in press*.